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(71)(72) Applicants and Inventors: RANGWALLA, Imtiaz [IN/US]; 21 Jetwood Street, N. Andover, MA 01845 (US). CLOUGH, Harvey [US/US]; 100 Tucker Farm Road, N. Andover, MA 01845 (US). McINTYRE, Frederic, S. [US/US]; 81 Royalston Road, Wellesley, MA 02181 (US).

(74) Agents: BEDNAREK, Michael, D. et al.; Kilpatrick & Cody, L.L.P., Suite 800, 700 13th Street, N.W., Washington, DC 20005 (US).

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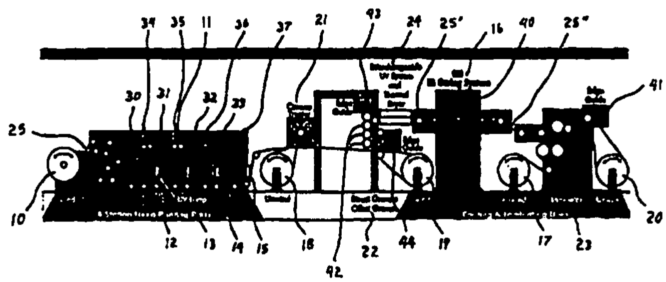

(57) Abstract

This invention is a printing system for applying and curing radiation curable inks to a flexible, heat shrinking web (25) employing a combination of ultraviolet "UV" radiation and electron beam "EB" radiation. The printing system includes an unwind station (10), a four-station flexo printing press (11) equipped with four interstation UV curing systems (12-15), an EB curing system (16), and a rewind station (17). The printing system includes a laminating station (23) for applying a laminate to a semi-dry printed web (25"), which can then be passed through the EB curing system (16) to produce finished packaging material. The arrangement of printing stations avoids a central impression cylinder and the associated heat build-up on the impression cylinder. The printing system also reduces or eliminates the need for a nitrogen gas atmosphere in the curing process.

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APPARATUS FOR APPLYING AND CURING RADIATION CURABLE INKS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates generally to a system and method for printing substrates for use in food packaging and, in particular, to a hybrid method and apparatus for use in applying and curing radiation curable inks to a flexible, heat shrinkable web employing a combination of ultraviolet ("UV") radiation and electron beam ("EB") radiation.

Description of the Related Art

In the food packaging art, flexographic printing processes and apparatus have been employed for applying print media to a flexible web of, for example, plastic material, which is thereafter used for packaging food products. The flexographic printing presses employed in such an application typically utilize a large central impression drum about which individual print stations are radially arrayed. Each of the print stations prints or lays down an individual color on the web. During the flexographic printing process it is necessary to dry the color laid down at a print station sufficiently before it reaches the next print station so

as to prevent smearing or pick-off of the ink at the succeeding print station.

The colors may be dried between successive print stations by blowing hot air on the web being printed, or by subjecting the web to ultraviolet radiation. Each of these methods requires different ink compositions. For example, for interstation drying using hot air, a solvent-based or water-based ink composition is used. For interstation drying using UV radiation, an ink composition having a radiation curable component must be used.

A major disadvantage associated with solvent-based ink compositions is that the solvent is evaporated from the inks during the ink drying process thereby releasing volatile organic chemicals into the atmosphere. Modern government regulations have required the reduction and, in some cases, the total elimination of the emission of these volatile organic chemicals into the atmosphere. In addition, there is an inherent explosive hazard associated with solvent-based ink compositions that are heat dried. Moreover, when a solvent-based ink is subjected to heat curing, a web shrinkage problem results. To avoid shrinkage, long ovens must be employed to gradually dry the web.

To eliminate the emissions and explosive hazard problems associated with the solvent-based ink compositions, water-based ink compositions have been increasingly used in flexographic printing systems. However, because water-based ink compositions are subjected to hot air blowing for interstation drying

during printing, these ink compositions suffer from the problems associated with printing on heat shrinkable flexible webs.

The use of radiation curable ink compositions in offset printing systems is known in the printing art. These radiation curable ink compositions require heavy loading of the ink with photo-initiators to promote the final ink curing by UV radiation. Such an ink composition is not suitable for printing flexible, heat shrinkable substrates for use in food packaging for the simple reason that the high loading of photo-initiators required to promote ink curing leads to high amounts of migratable or extractable monomers. The high amount of migratable or extractable monomers would fail to meet FDA requirements for packaging materials having incidental food contact.

A further problem associated with UV radiation curable ink compositions is the high level of energy input required to affect final curing of the ink composition. Food packaging applications are often highly abusive applications and, therefore, high energy level input is required for final curing of these ink compositions to a point where they can be successfully used on the outside surface of the package.

When applying a UV curable ink composition to a flexographic printing system further problems arise. The nature of the flexographic printing system that required a plurality of radially arrayed printing stations would require individual UV radiation systems to be incorporated between each printing stations for curing

the ink laid down at the printing station before printing at a successive printing station. In light of the high energy level input required by each of these UV curing and drying systems, energy costs for operating a flexographic printing system employing UV radiation curable inks does not appear to be commercially viable, particularly for the heat shrinkable webs. In addition, high intensity UV lamps radiate about 50% of their energy as infrared energy, which results in a heating of the central impression drum.

The use of EB radiation to cure inks is known in the printing art, but there currently exist various limitations. For example, EB equipment is too large and expensive to be placed between all printing stations in a printing press. The cost of EB equipment is typically 10 times higher than the cost of a single UV lamp curing system. Moreover, EB curing of wet inks and coatings requires the use of an inert gas, like nitrogen, in place of an atmosphere containing oxygen at the point of cure. Traditional EB inks/coatings will not cure in the presence of oxygen in quantities as low as 300 parts per million. Nitrogen usage cost is often $15 to $20 per hour for a single printing press.

Because of these limitations, the use of EB curing has mostly been limited to packaging materials printed by the "offset" printing process. The "offset" method employs successive wet ink applications upon each other without interstation drying. This method is applicable to absorbent substrates of paper and

paperboard. Plastic films are not, however, suitable for offset printing.

Other printing processes such as Gravure, Flexographic, letter press, and screen printing typically require that the ink be at least partially cured between each printing step. These inks are formulated specifically for the printing method, quantity of ink deposited, substrate properties, and drying/curing method.

Efforts have been made to combine UV radiation and EB radiation in the past, as reflected by UK Patent Specification No. 1 381 805, U.S. Patent No. 5,407,708 and U.S. Patent No. 3,936,557. However, the systems and processes disclosed in these patents are not entirely satisfactory for combining multiple curing technologies to overcome the limitations and narrow end-use of EB curing in the manufacture of food packaging materials.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to meet the above-stated needs and others. More particularly, it is an object of the present invention to combine multiple curing technologies to overcome the limitations and narrow end-use of EB curing in the manufacturing of food packaging materials.

It is a further object of the present invention to provide a system and process for applying a laminate to a semi-dry printed web followed by an EB radiation cure to produce finished packaging material.

It is a further object of the present invention to provide an arrangement of printing stations that avoid a central impression cylinder and associated heat build-up on the impression cylinder.

It is a further object of the present invention to provide a system and process for applying and curing an ink on packaging materials with reduction or elimination of an inert gas atmosphere in the curing process. In other words, it is an object of the present invention to provide a method and apparatus for applying and curing ink in ambient atmosphere.

Additional objects, advantages and novel features of the invention will be set forth in the description which follows or may be learned by those skilled in the art through reading these materials or practicing the invention. The objects and advantages of the invention may be achieved through the means recited in the attached claims.

To achieve the stated and other objects of the present invention, as embodied and described below, the invention may comprise: a first unwind station for paying out the web of substrate material and a plurality of print station assemblies. Each print station assembly includes a print station for applying a coating of radiation curable ink to the substrate, a guide roller arranged downstream from the print station and arranged so as to guide the web of substrate material away from the print station. The guide roller is spaced from the printing roll and back-up support roll of the print station so as to provide an exposed length of the web of

substrate material that is not in contact with any of the back-up support roll, printing roll and guide roller. A UV lamp, preferably operated at a power level of 100 watts per inch of lamp length or less, is arranged adjacent the exposed length of the web of substrate material for partially curing the coating of ink on the web of substrate material. Electron beam radiation means are provided downstream of the print stations for finally curing the coatings of ink.

Each of the print stations of the present invention preferably include a fluid reservoir containing an ink or coating. A partially submerged machine-driven roll is placed in contact with the ink/coating material. Each machine-driven roll is surface etched with controlled depth recesses to provide a multitude of small reservoirs. A doctor blade contacts the full surface width of the machine-driven rolls so as to remove excess coating material during operation, leaving the remainder of ink or coating within the recesses. A drum rubber-covered roll is in contact with the doctored surface of the machine-driven roll for receiving the ink or coating material from the recesses. A driven printing plate roll having raised surface areas is in contact with the rubber roll and for receiving ink and a back-up support roll is provided so that in operation the web substrate is passed between the printing plate roll and a driven back-up support roll to transfer the ink or other coating to the web substrate.

The electron beam radiation means of the present invention preferably comprises an electron beam

curing system that operates at a voltage that is adjustable from 125 to 150 kV. The electron beam curing system preferably provides a cure dose of 0.5 to 6 megarads (Mrads) when operating at a process speed between 300 fpm to 500 fpm.

The system may further include a high power (up to 400 watts of UV radiation per square inch of printed web) UV curing station located downstream of all of the print station assemblies for providing a final cure of the UV curable components of the inks/coatings. The system may also include a laminator, located downstream of the electron beam radiation means, for laminating a second web (printed or non-printed) to a side of the web of substrate material. The system may also include coating means for providing a curable top coat varnish over the printed surface, the coating means located upstream of the electron beam radiation means so that the electron beam radiation means cures the top coat varnish as well as the coatings of ink.

The system may also include a corona treating station located downstream of the printing stations for providing an electrical discharge and treatment to one surface of the web of substrate material. The treatment level provided by the corona treating station is preferably in the range of 30 to 50 dynes. To allow separate use of the corona treating station, the system may also include a corona treatment unwind station located adjacent the corona treating station for paying out a web of substrate material. The corona treatment unwind station is preferably arranged so that the corona

treating station can process both a web of substrate from the printing stations and a web of substrate paid out by corona treatment unwind station.

The system may also include a gravure printing station located downstream of the second printing station for applying liquid coatings to the web of substrate material. The gravure coating station preferably has interchangeable gravure cylinders having specific etched fluid recessions for applying a specific coat weight of fluid. To allow separate use of the gravure printing station, the system may also include a gravure printing unwind station located adjacent the gravure printing station for paying out a web of substrate material, the gravure printing unwind station being arranged so that the gravure printing station can process both a web of substrate from the printing stations and a web of substrate paid out by gravure printing unwind station.

The system may also include a coating laminating system that includes a laminating station located on top of the gravure coating station such that the gravure roll and laminating roll are machine-driven in a synchronized and/or proportional manner. As a result, two webs may be introduced into the coating laminating system, namely a first printed web and a second web from the unwind station adjacent the gravure coating station that passes through the gravure coating station and receives a coating of lamination adhesives, whereby following the adhesive application while the adhesive is still wet, the printed web is laminated and

the laminated web is then passed into the electron beam radiation means for curing the adhesive coating.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawing illustrates the present invention and is a part of the specification. Together with the following description, the drawing demonstrates and explains the principles of the present invention.

Figure 1 is a schematic representation of a printing system that employs radiation curable inks and a combined UV-EB curing system in accordance with the present invention;

Figure 2 presents the evaporative rate analysis for Treatments 1 and 2 in Example 2;

Figure 3 presents the evaporative rate analysis for Treatment 4 in Example 2; and

Figure 4 presents the evaporative rate analysis for Treatment 5 in Example 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Using the drawing, the preferred embodiment of the present invention will now be explained. All examples are merely illustrative. As will be recognized by those of ordinary skill in the art, the principles of the invention are applicable to printing processes other than those specifically described. As used in this application, the term "downstream" refers to a location or direction of web movement that is toward the latter stages of processing. Conversely, the term "upstream"

refers to a location that is toward a portion of the web processing sequence closer to the basic untreated web. In Figure 1, the web moves from left (upstream) to right (downstream).

Referring to Figure 1, the preferred embodiment of the hybrid UV/EB printing system and process will be described. The printing system includes an unwind station **10** adjacent a four-station flexo printing press **11** equipped with four UV curing systems **12**, **13**, **14**, **15**. The four-station printing press **11** eliminates the use of printing stations spaced around a central impression cylinder and, therefore, avoids heat build-up on the impression cylinder. An EB curing system **16** and a rewind station **17** are provided downstream of the four-station printing press **11**.

The system according to the present invention also preferably includes a first unwind station **18**, a second unwind station **19**, a third unwind station **20**, a corona treatment system **21**, a gravure roll coating station **22**, a laminating station **23**, and a UV cure unit **24**.

A more detailed description of the preferred specifications and purpose of each equipment station will next be provided.

The unwind station **10** adjacent the printing press **11** is designed to provide a roll unwinding station for processing films, paper, and/or paperboard into the printing press **11**. The unwind station **10** can, for example, handle a web width of 6" to 13" and a speed range of 0 to 500 fpm (175 m/m), and provide an

adjustable tension in the web **25** in the range of 100 to 2000 grains per inch of web width. A web edge guide alignment system in the unwind station **10** controls edge position alignment to + or - 0.010 inches.

The unwind station **10** provides controlled web tension and stretch prior to the web **25** entering the printing press **11**. Controlled tension ensures close tolerance of print registration of each color with respect to each other as the web **25** progresses through the printing stations of the printing press **11**.

The four-station flexo printing press **11** is designed to print up to four colors onto a continuous web substrate. The printing method is preferably flexographic, but may include other printing methods as well. The inks applied by the printing press **11** are curable by a combination of UV and EB radiation. The printing press **11** preferably handles a web speed in the range of 300 fpm (90 m/m) to 500 fpm (175 m/m), and has an enclosed ink chamber and a doctor blade system, as described below.

A UV curing system **12**, **13**, **14**, **15** is located after each print station in the printing press **11**. The UV power output from the UV curing systems at each print station is adjustable in increments from 100 to 400 watts per inch of lamp length. The UV power output can be manually set or synchronized to speed, e.g., an incremental power level increase upon an increase in speed.

The four-station printing press **11** provides a means of printing up to four hybrid inks/coatings to a

film, paper, or paperboard substrate. Separate printing stations with separate impression cylinders are provided in the printing press **11**, instead of printing stations spaced around a central impression cylinder, to avoid heat build up on the impression cylinders. The hybrid inks/coatings are partially cured by the single UV lamp systems **12**, **13**, **14**, **15** located after each print station. The degree of UV partial cure is sufficient to provide a non-wet ink/coating surface, which allows surface contact by the printing rolls without transfer of the ink/coating.

The hybrid UV inks/coatings are partially cured by low power UV energy (i.e. 100 watts). The partial cure is preferably obtained at process speeds of 1 to 300 fpm via the single UV lamp systems **12**, **13**, **14**, **15** at 100 watts per inch of lamp length. New ink additives employing photoinitiators provide partial curing to speeds of 500 fpm with the same amount of UV energy. The partial cure is obtained with inks/coatings deposits ranging from 2 gsm to 25 gsm. A range of deposits is obtained by an ink transfer and printing system used in flexographic printing.

Other features of the invention will become apparent in the course of the following description of exemplary embodiments which are given for illustration of the invention and are not intended to be limiting thereof.

Example 1

To demonstrate the controlled depth of crosslinking achieved with the present invention, four 2.5 mil thick polyolefin films were each equipped with four 10 micron radiochromic dosimeters (FarWest Technology, Goleta, GA), two of which were taped to the top side of each film and two taped to the bottom side. The dosimeters change from colorless to blue upon exposure to EB radiation. By measuring the intensity of the color change, the dose delivered to the two sides of each film can be measured in millirads. The four films were then run under different operating conditions on an ESI Pilot Electrocurtain, in which the films were placed on a polyethylene terephthalate (PET) carrier web for transport through the unit. The operating conditions of the processor and the dosimeter results are provided in Table 1.

Table 1

Film #	Voltage, kV	Beam Current, mA	Product Speed, fpm	Dose at Top Side (D_T)	Dose at Bottom Side (D_B)	D_T/D_B
1	90	14.3	20	2.5	0.2	12.5
2	100	10.0	20	7.5	1.0	7.5
3	110	7.1	20	11.0	4.0	2.8
4	150	5.0	20	3.8	3.8	1.1

From such results, it is clear the present system provides the ability to deliver electrons where required.

Example 2

To demonstrate the advantages provided by the present invention, five polyvinyl chloride films were printed with a UV/EB curable ink manufactured by International Inks, Warminster, PA, Product No. P50297 in accordance with five different procedures identified in Table 2 and the cured quality of the printed product was assessed by means of evaporative rate analysis. In the first treatment, the film was printed and the printed product cured by means of EB radiation at 170 kV to a 1 Mrad dose in a nitrogen atmosphere (<50 ppm O_2). In the second treatment, the film was printed and the printed product cured by means of EB radiation at 170 kV to a 4 Mrad dose in a nitrogen atmosphere (<50 ppm O_2). In the third treatment, the film was printed and the printed product cured by means of EB radiation at 170 kV to a 2.5 Mrad dose in ambient atmosphere (air). In the fourth treatment, the film was printed and the printed product cured by means of EB radiation at 170 kV to a 2.5 Mrad dose in a nitrogen atmosphere (<50 ppm O_2). In the fifth treatment, the film was printed and the printed product was partially cured by means of UV radiation at 200 watts/inch at 20 feet/minute and subsequently cured by means of EB radiation at 170 kV to a 2.5 Mrad dose in ambient atmosphere (air).

The curing was analyzed by means of evaporative rate analysis, in which an 18 mL droplet of test solution tagged with a compound containing ^{14}C at one part per 100,000 was applied to the cured film surface. The

detector head was put in place and data collection begun. A plot of the log of ^{14}C counts versus time was generated. A lightly cross-linked polymer will swell to a greater degree than a highly crosslinked material, allowing the tagged compound to penetrate the surface. When solvent swell and penetration occur, the ^{14}C count is high with respect to time. Highly crosslinked materials swell to a lesser degree, and ^{14}C counts decrease with respect to time more rapidly.

The results of four of the five cure treatments are presented in Figures 2, 3, and 4. Figure 2 represents the evaporative rate analyses for Treatments 1 and 2. Treatment 3 did not cure and, accordingly, no evaporative rate analysis was performed. Figure 3 presents the results for Treatment 4, while the results of Treatment 5 are presented in Figure 4.

The conclusions which can be drawn from the experimental results are (1) an EB cure, by itself, requires an inert atmosphere; (2) a treatment dose of 4 Mrads produces a more thorough cure than that achieved with 1 Mrad; (3) a partial cure with UV, followed by a subsequent cure with EB at 2.5 Mrad, produces a more thorough cure than an EB cure at 4 Mrads, by itself; and (4) a partial cure with UV, followed by a subsequent cure with EB at 2.5 Mrad, can be achieved in ambient atmosphere.

Table 2

Treatment #	Treatment	Atmosphere
1	EB, 170 kV, 1 Mrad	N_2 (<50 ppm O_2)
2	EB, 170 kV, 4 Mrad	N_2 (<50 ppm O_2)
3	EB, 170 kV, 2.5 Mrad	Ambient (Air)
4	EB, 170 kV, 2.5 Mrad	N_2 (<50 ppm O_2)
5	UV, 200 W/in, 20 fpm; EB, 170 kV, 2.5 Mrad	Ambient (Air)

These results demonstrate that the method and apparatus of the present invention provide a more thorough cure than either UV alone or EB alone. These results also demonstrate, surprisingly, that a thorough cure can be achieved in ambient atmosphere and that a thorough cure can be achieved with a lower dosage EB cure than is conventionally required (2.5 Mrad versus the 4.0 Mrad doasge conventionally required).

The flexographic printing process used by each of the four stations in the flexo printing press **11** includes fluid reservoirs **30, 31, 32, 33**, each containing an ink/coating, and a partially submerged machine-driven roll **34, 35, 36, 37** (analox) placed in contact with the ink/coating material. Each analox roll **34, 35, 36, 37** is surface-etched with controlled depth recesses to provide a multitude of small reservoirs. Interchangeable analox rolls provide specific reservoir recess capacity to obtain lower or higher ink transfer. A doctor blade contacts the full surface width of the analox rolls **34, 35, 36, 37**. During operation, the excess coating material is removed by the doctor blade, leaving the remainder of ink/coating within the recesses.

A drum rubber-covered roll contacts the doctored surface of the analox roll and receives the

ink/coating material from the recesses. The driven flexo printing plate roll contacts the rubber roll and receives ink transfer to the raised surface areas of the printing plate. The web substrate is passed between the flexo printing plate roll and a driven back-up support roll, and the ink/coating is thereby transferred to the web substrate.

The electron beam curing system **16** is designed to generate electrons for providing a final curing of inks/coatings on the printed web. An accelerator voltage of the electron beam curing system **16** is preferably adjustable from 125 to 150 kV. The 150 kV voltage operation is suitable for curing inks/coatings up to 70 microns of thickness, while the 125 kV voltage operation is suitable for curing inks/coatings from 1 to 25 microns of thickness. The EB curing system **16** preferably handles a web width of up to 18" at a process speed of 300 fpm to 500 fpm and provides a cure dose of 0.5 to 6 megarads.

In operation, the printed/coated web **25'** enters relatively horizontal into the left side of the EB curing system **16** with the partially cured coating located on the top surface of the web **25'**. The electron beam generator **40** in the EB curing system **16** is operated to emit electron beam radiation. The electrons exit the generator **40** downward and penetrate into the partially cured top surface of the printed/coated web **25'**. The hybrid inks/coatings are designed to polymerize/crosslink upon impact of the electrons. The uncured components of the inks/coatings are converted instantaneously into a solid, cured state. The web **25"** containing the fully

cured inks/coatings exits the right side of the EB curing system **16**.

The rewind system **17** contains idler and driven rolls for rewinding various substrates of film, paper, and paperboard. The web rewind system **17** is positioned to the right side of the EB curing system **16**. The rewind system **17** preferably handles a web width of 18" and a process speed of 300 to 500 fpm. The rewind system **17** provides a rewind tension in the range of 250 grams to 2000 grams per inch of web width. The rewind system **17** provides a means of pulling the cured ink/coated web substrate **25"** from successive process stations and winding the cured web substrate up on a roll ready for further processing.

The unwind station **20** on the right-hand side of the printing system is designed to provide a roll method for processing films, paper, and paperboard into a coating station and/or laminating station **23**. The unwind station **20** preferably handles a web width of up to 18" and a speed range of 0 to 500 fpm. The unwind station **20** provides an unwind tension in the range of 100 to 2000 grams per inch of web width. A web edge guide alignment system **41** provides edge position accuracy of + or - 0.010 inches.

The unwind station **20** provides controlled web tension and stretch prior to the web **25"** entering the coating or laminating station **23**. The tension control of the unwind station **20** is adjustable and provides a means of obtaining acceptable coating material deposits onto

the web **25"**, or a balanced web tension for laminating to a second web.

The unwind station **19** adjacent the gravure coating station **22** and the unwind station **18** adjacent the corona treating station **21** both have structures and operations similar to the unwind station **20** adjacent the laminating station **23**. The unwind station **19** adjacent the gravure coating station **22** provides controlled web tension and stretch prior to the web entering the gravure coating station **22**. The unwind station **18** adjacent the corona treating station **21** provides controlled web tension and stretch prior to the web entering the corona treating station **21**.

The corona treating station **21** provides an electrical discharge treatment to one surface of the web substrate. The corona treating station **21** preferably handles a web width of up to 18" and a process speed of 0 to 500 fpm. The treatment level provided by the corona treating station **21** is preferably in the range of 30 to 50 dynes.

In operation, the corona treating station **21** alters the surface energy of films, paper, and paperboard materials. The corona treating station **21** introduces a surface preparation that enhances the adhesion properties of inks/coatings deposits. The typical treatment levels used are 30 to 45 dynes. The unwind station **18** adjacent the corona treating station **21** and the printed web from the flexo press **11** are easily processed through the corona treating station **21**, after which subsequent coatings and/or laminations will occur.

The gravure coating station **22** provides a means for applying liquid coatings to the web substrate. The gravure coating station **22** has interchangeable gravure cylinders **42** having specific etched fluid recessions for applying a specific coat weight of fluid. Typical coat weights applied by the gravure coating station **22** range from 0.5 to 10 grams per square meter. The gravure coating station **22** preferably has gravure roll widths of 20" and handles webs at process speeds of 0 to 5 fpm. The gravure coating station **22** is designed to handle a coating material having a viscosity of 1 to 30,000 centipoise at 70° F. A second laminating station can be located on top of the gravure coating station **22**. The gravure roll and laminating roll are machine-driven in a synchronized and/or proportional manner with respect to the web process speed. Web edge guide alignment systems **43**, **44** are provided adjacent the gravure printing station **22** to ensure edge position accuracy during the gravure printing process.

For preparing a non-laminated coated web, a printed web from the printing press (left side) or a preprinted web from the unwind station **19** adjacent the gravure coating station **22** passes through the gravure coating station **22**. A coating is applied to the underside of the web (printed or non-printed side) after which the web passes into the UV curing station **24**, then into the EB curing system **16** for the final cure.

The operation for preparing a laminated coated web is similar to the above description, except that two webs are introduced into the coating laminating system

23. A printing web from the printing press (left side) or a preprinted web from the unwind station **20** adjacent the laminating station **23** passes upward and to the laminating station **23**. A second web from the unwind station **19** adjacent the gravure coating station **22** passes through the gravure coating station **22** and receives a coating of lamination adhesives. Immediately following the adhesive application while the adhesive is still wet, the printed web is laminated. The laminated web is then passed into the EB curing system **16** for instant cure.

The UV curing station **24** adjacent the EB curing system provides a final cure of the UV curable components of the inks/coatings. The UV curing station preferably provides up to 400 watts of UV radiation per square inch of printed web. The UV power in the UV curing station **24** is adjustable by voltage variation to 100 watts. The UV power may or may not be synchronous to the web speed. The hybrid coatings of the printed web pass under UV lamps in the UV curing station **24** for a partial cure immediately followed by an EB finish cure by the EB curing system **16**.

The advantages of the system and process of the present invention include, but are not limited to, the following:

(1) The UV curing stations can be operated at a "low power" level (i.e., 100 watts per inch of lamp length) compared to a high power level of 400 watts or more used by existing systems. The low power UV curing (100 watts), as compared to the high power UV curing (300 watts), reduces the IR (infrared heat) by 67% or more.

(2) The low power UV with reduced IR permits curing of hybrid inks/coatings in heat sensitive films and other substrates. High power UV cure systems (300 watts or more) produce high levels of IR, which causes shrinkage, softening, or melting of printed plastic films during UV curing, or severe moisture loss and shrinkage in paper substrates. The low power UV of the present invention provides adequate cure at all normal printing press speeds up to 500 feet per minute.

(3) A wide variety of printing station configurations are compatible with the hybrid curing teachings of the present invention. The additional coatings and laminating stations located throughout the process line provide the following process line capabilities: a hybrid curable top coat varnish over the printed surface; a lamination of a second (printed or non-printed) web to the underside or top side of the first printed web; and multiple laminations.

(4) The EB radiation finish cure provides instant and complete polymerization/crosslinking of inks/coatings of packaging materials. These materials are then ready for final converting in a packaging line. Traditional "work in process" inventory storage is eliminated by the instant complete cure.

(5) The base packaging materials processed through the hybrid curing process of the present invention maintain their original physical condition without shrinkage, and the cured inks/coatings demonstrate the highest degree cure available.

The preceding description has been presented only to illustrate and describe the invention. It is not intended to be exhaustive or to limit the invention to any precise form disclosed. Many modifications and variations are possible in light of the above teaching.

The preferred embodiment was chosen and described in order to best explain the principles of the invention and its practical application. The preceding description is intended to enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims.

WHAT IS CLAIMED IS:

1. A system for applying and curing radiation curable inks to a web of substrate material comprising:

a first unwind station for paying out the web of substrate material;

a first print station for applying a first coating of radiation curable ink to the substrate, the first print station comprising a printing roll and an back-up support roll arranged such that the web of substrate material passes between the printing roll and the back-up support roll;

a first guide roller arranged downstream from the first print station and arranged so as to guide the web of substrate material away from the first print station, the guide roller being spaced from the printing roll and back-up support roll of the first print station so as to provide a first exposed length of the web of substrate material that is not in contact with any of the back-up support roll, printing roll and first guide roller;

a first UV lamp arranged adjacent the first exposed length of the web of substrate material for partially curing the first coating of ink on the web of substrate material;

a second print station for applying a second coating of radiation curable ink to the substrate, the second print station comprising a printing roll and an back-up support roll arranged such that the web of

substrate material passes between the printing roll and the back-up support roll;

a second guide roller arranged downstream from the second print station and arranged so as to guide the web of substrate material away from the second print station, the guide roller being spaced from the printing roll and back-up support roll of the second print station so as to provide a second exposed length of the web of substrate material that is not in contact with any of the back-up support roll, printing roll and second guide roller;

a second UV lamp arranged adjacent the second exposed length of the web of substrate material for partially curing the second coating of ink on the web of substrate material; and

electron beam radiation means downstream of the second print station for finally curing the first coating of ink and the second coating of ink.

2. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, further comprising:

a third print station for applying a third coating of radiation curable ink to the substrate, the third print station comprising a printing roll and an back-up support roll arranged such that the web of substrate material passes between the printing roll and the back-up support roll;

a third guide roller arranged downstream from the third print station and arranged so as to guide the

web of substrate material away from the third print station, the guide roller being spaced from the printing roll and back-up support roll of the third print station so as to provide a third exposed length of the web of substrate material that is not in contact with any of the back-up support roll, printing roll and third guide roller;

a third UV lamp arranged adjacent the third exposed length of the web of substrate material for partially curing the third coating of ink on the web of substrate material;

a fourth print station for applying a fourth coating of radiation curable ink to the substrate, the fourth print station comprising a printing roll and an back-up support roll arranged such that the web of substrate material passes between the printing roll and the back-up support roll;

a fourth guide roller arranged downstream from the fourth print station and arranged so as to guide the web of substrate material away from the fourth print station, the guide roller being spaced from the printing roll and back-up support roll of the fourth print station so as to provide a fourth exposed length of the web of substrate material that is not in contact with any of the back-up support roll, printing roll and fourth guide roller;

a fourth UV lamp arranged adjacent the fourth exposed length of the web of substrate material for partially curing the fourth coating of ink on the web of substrate material; and

wherein the electron beam radiation means is located downstream of the fourth print station for finally curing the first, second, third and fourth coatings of ink.

3. The system for applying and curing radiation curable inks to a web of substrate material according to claim 2, further comprising a final UV curing station located downstream of the fourth UV lamp and adjacent the electron beam radiation means, the final UV curing station operating at a higher power than the UV lamps for providing a final cure of the UV curable components of the inks/coatings.

4. The system for applying and curing radiation curable inks to a web of substrate material according to claim 2, wherein the final UV curing station provides up to 400 watts of UV radiation per square inch of printed web.

5. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, further comprising a laminator, located downstream of the electron beam radiation means, for laminating a second web to a side of the web of substrate material.

6. The system for applying and curing radiation curable inks to a web of substrate material according to claim 5, wherein the second web is printed.

7. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1,

further comprising coating means for providing a curable top coat varnish over the printed surface, the coating means being located upstream of the electron beam radiation means so that the electron beam radiation means cures the top coat varnish as well as the first coating of ink and the second coating of ink.

8. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, wherein the first and second UV lamps are operated at a power level of 100 watts per inch of lamp length or less.

9. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, wherein each of the print stations comprise:

a fluid reservoir containing an ink or coating;

a partially submerged machine-driven roll placed in contact with the ink/coating material, each machine-driven roll being surface etched with controlled depth recesses to provide a multitude of small reservoirs;

a doctor blade contacts the full surface width of the machine-driven rolls so as to remove excess coating material during operation leaving the remainder of ink or coating within the recesses;

a drum rubber covered roll in contact with the doctored surface of the machine-driven roll for receiving the ink or coating material from the recesses;

a driven printing plate roll having raised surface areas in contact with the rubber roll and for receiving ink; and

a back-up support roll;

whereby in operation the web substrate is passed between the printing plate roll and a driven back-up support roll, and the ink/coating is thereby transferred to the web substrate.

10. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, wherein the electron beam radiation means comprises an electron beam curing system that operates at a voltage that is adjustable from 125 to 150 kV.

11. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, wherein the electron beam radiation means comprises an electron beam curing system that provides a cure dose of 0.5 to 6 megarads when operating at a process speed between 300 fpm to 500 fpm.

12. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, further comprising a second unwind station located downstream of the second printing station for paying out a web of substrate material, the second unwind station providing controlled web tension and stretch to the web.

13. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, further comprising a corona treating station located downstream of the second printing station for providing

an electrical discharge and treatment to one surface of the web of substrate material.

14. The system for applying and curing radiation curable inks to a web of substrate material according to claim 13, wherein the treatment level provided by the corona treating station is in the range of 30 to 50 dynes.

15. The system for applying and curing radiation curable inks to a web of substrate material according to claim 13, further comprising a corona treatment unwind station located adjacent the corona treating station for paying out a web of substrate material, the corona treatment unwind station being arranged so that the corona treating station can process both a web of substrate from the printing stations and a web of substrate paid out by corona treatment unwind station.

16. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, further comprising a gravure printing station located downstream of the second printing station for applying liquid coatings to the web of substrate material.

17. The system for applying and curing radiation curable inks to a web of substrate material according to claim 16, further comprising a gravure printing unwind station located adjacent the gravure printing station for paying out a web of substrate material, the gravure printing unwind station being arranged so that the gravure

printing station can process both a web of substrate from the printing stations and a web of substrate paid out by gravure printing unwind station.

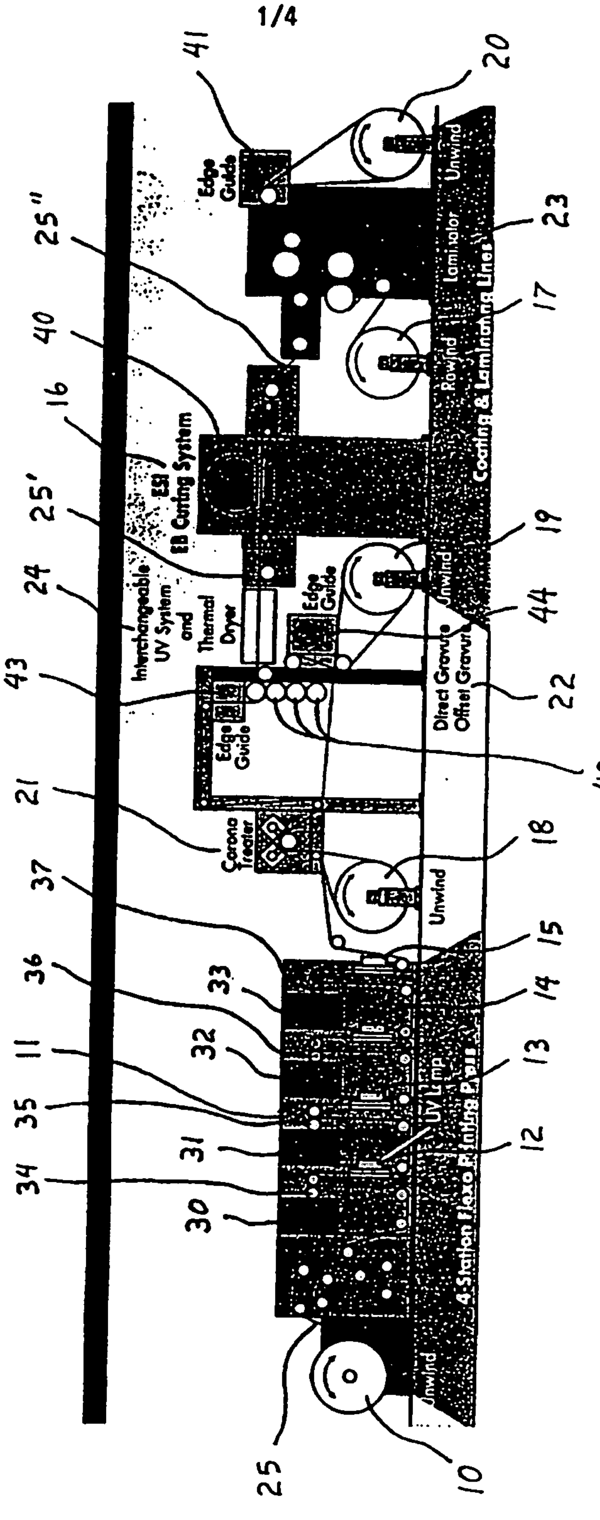
18. The system for applying and curing radiation curable inks to a web of substrate material according to claim 16, wherein the gravure coating station has interchangeable gravure cylinders having specific etched fluid recessions for applying a specific coat weight of fluid.

19. The system for applying and curing radiation curable inks to a web of substrate material according to claim 16, further comprising a coating laminating system including a laminating station located on top of the gravure coating station such that the gravure roll and laminating roll are machine-driven in a synchronized and/or proportional manner, whereby two webs may be introduced into the coating laminating system, namely a first printed web and a second web from the unwind station adjacent the gravure coating station that passes through the gravure coating station and receives a coating of lamination adhesives, whereby following the adhesive application while the adhesive is still wet, the printed web is laminated and the laminated web is then passed into the electron beam radiation means for curing the adhesive coating.

20. The system for applying and curing radiation curable inks to a web of substrate material according to claim

16, further comprising a third unwind station located adjacent the gravure coating station for paying out a web of substrate material.

21. The system for applying and curing radiation curable inks to a web of substrate material according to claim 1, wherein said final curing by electron beam means is conducted in an ambient atmosphere.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Unwind
Laminator
Rewind
Coating & Laminating Lines
ESI
EB Coating System
Interchangeable UV System and Thermal Dryer
Edge Guide
Unwind
Direct Gravure
Offset Gravure
Edge Guide
Corona Treater
Unwind
UV Lamp
4 Station Flexo Printing Press
Unwind
41
20
25"
23
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17
16
25'
19
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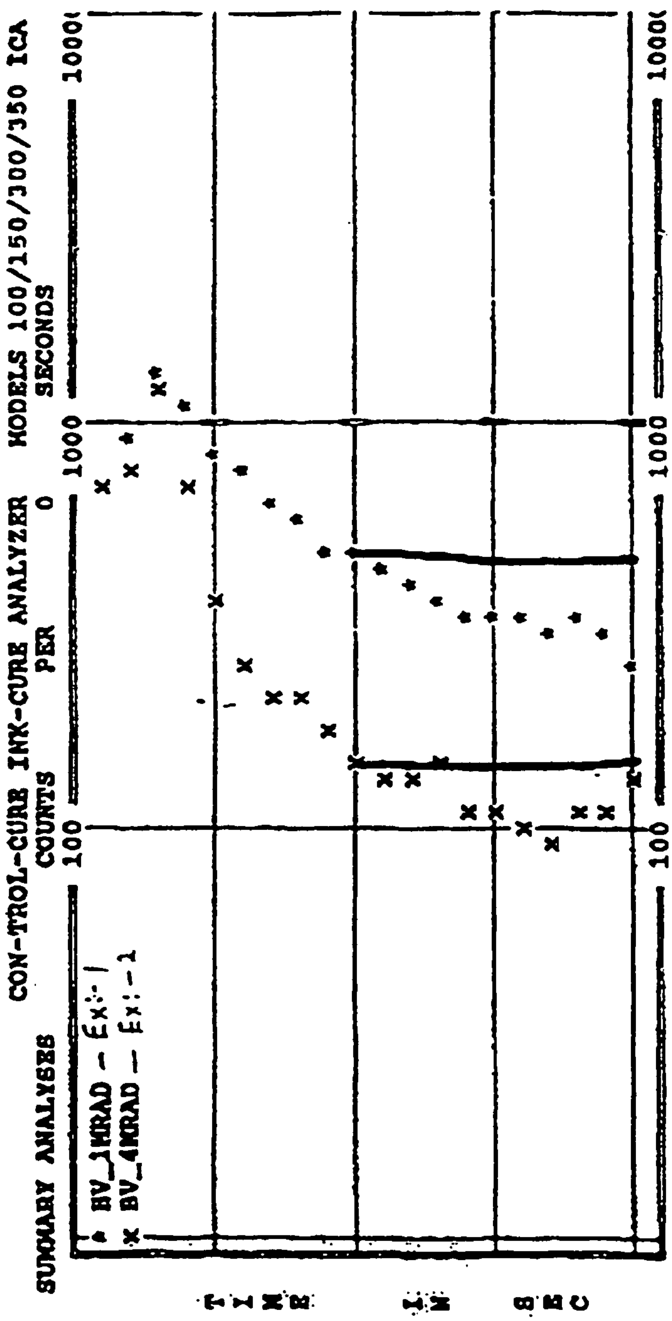
FIGURE 1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CON-TROL-CURE INK-CURE ANALYZER MODELS 100/150/300/350 ICA
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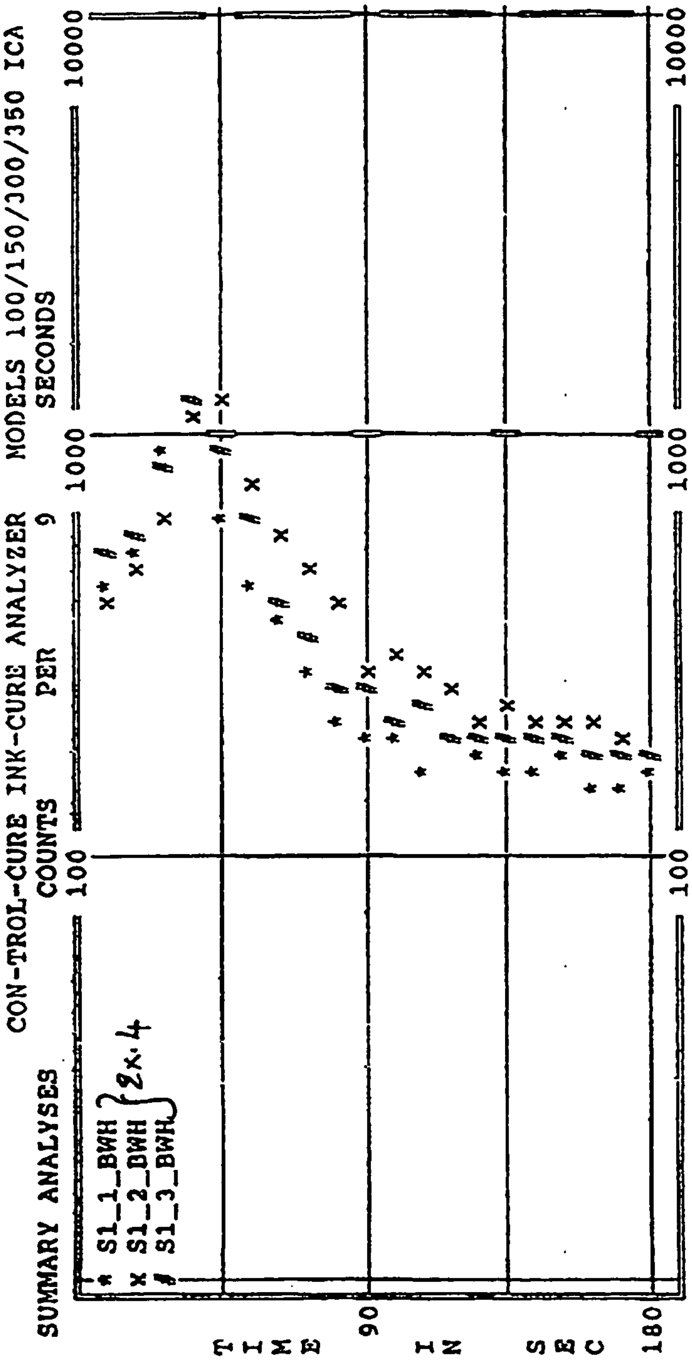
x BV_4MRAD — Ex:-1
100
1000
10000
0
TIME IN SEC

FIGURE 2


SUMMARY ANALYSES
CON-TROL-CURE INK-CURE ANALYZER
MODELS 100/150/300/350 ICA
COUNTS PER 9 SECONDS
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x S1_2_BWH
S1_3_BWH
Ex. 4
100
1000
10000
TIME IN SEC
90
180

FIGURE 3

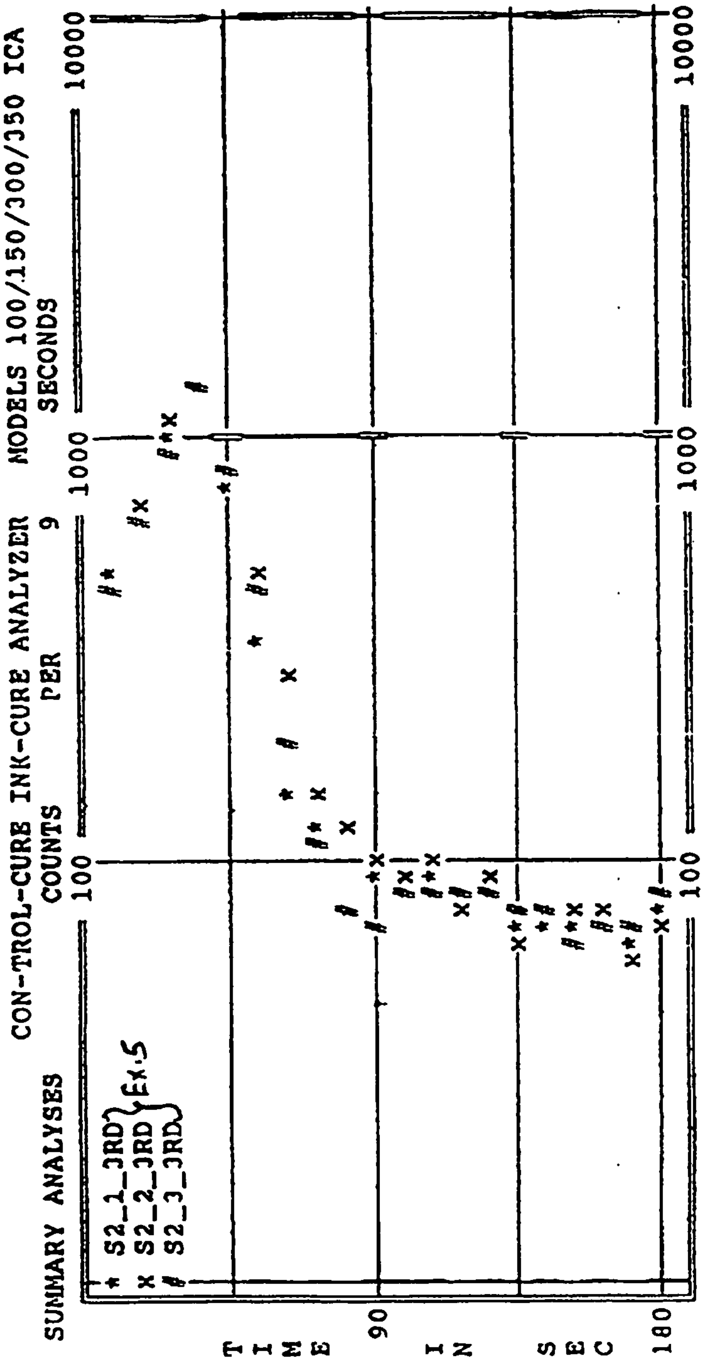
SUMMARY ANALYSES
CON-TROL-CURE INK-CURE ANALYZER MODELS 100/150/300/350 ICA
COUNTS PER 9 SECONDS
100
1000
10000
* S2_1_3RD
X S2_2_3RD
S2_3_3RD
EX.5
TIME IN SEC
90
180

FIGURE 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/18557

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :BO5D 1/38; B41F 23/00
US CL :101/424.1; 156/277, 324; 427/493
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,407,708 A (LOVIN et al) 18 April 1995, entire document.	1-14, 16, 18, 20
Y	US 4,658,723 A (TOKUNO et al) 21 April 1987, Figs. 1 and 3.	1-14, 16, 18, 20
Y	US 3,960,081 A (GUSTAVS et al) 01 June 1976, Figs. 1 and 6.	3
Y	US 5,108,531 A (QUADRACCI) 28 April 1992, Fig. 1.	5, 6
Y	US 5,249,828 A (AXELROD) 05 October 1993, col. 2, lines 15-33.	7
Y	US 4,782,753 A (BOLZA-SCHUNEMANN) 08 November 1988, Fig. 1; and col. 4, lines 18-59.	9

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 FEBRUARY 1997	03 MAR 1997

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Stacia Sinnik for STEPHEN FUNK
Facsimile No. (703) 305-3590	Telephone No. (703) 308-0982

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/18557

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,405,475 A (KRAFT et al) 11 April 1995, col. 7, lines 54-65.	12
Y	US 4,008,352 A (DAWES et al) 15 February 1977, Abstract.	13, 14
Y	US 3,952,119 A (BUHLER) 20 April 1976, Fig. 1; and col. 3, lines 52-61.	16, 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/18557

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

101/151-153, 170, 178, 181, 219, 228, 350, 364, 424.1, 488, 491; 156/272.6, 275.5, 277, 324; 427/493, 496, 500, 504, 508, 510, 552, 558